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Promoting preservice teachers' critical thinking skills by inquiry-based chemical experiment

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Abstract

This study was designed to investigate the effects of inquiry chemical experiment in chemistry teaching in promoting preservice teachers' critical thinking skills. A pretest and posttest experimental design with a comparison group was employed to validate the effectiveness of the proposed approach. Ten chemical experiments were selected, and 42 chemical preservice teachers aged at 19-22 voluntarily participated in the research. The California Critical Thinking Skills Test (CCTST) was used to assess the level of preservice teachers' critical thinking skills. The CCTST pre and post scores of the preservice teachers in chemical inquiry experiments training have significant differences, which show that the inquiry chemical experiment has certain promoter action to the preservice teachers' critical thinking skills. The findings indicated that the implementation of inquiry chemical experiment improved critical thinking skills of the preservice teachers significantly.

Keywords: Critical thinking skill; inquiry chemical experiment; preservice teacher.

1. Introduction

John Dewey (1933) stated that the central purpose of education is learning to think. As part of that education, learners need to develop and learn to effectively apply critical thinking (CT) skills to their academic studies (Kealey, Holland, & Watson, 2005), to the complex problems that they will face in their professions (Yeh, 2004), and to the critical choices they will be forced to make as a result of the information explosion and other rapid technological changes (Oliver & Utermonhlen, 1995).

There are many definitions of critical thinking. Richard Paul (1988) calls it the ability to reach sound conclusions based on observation and information. Barry Beyer (1983) describes it as assessing the authenticity, accuracy and worth of knowledge claims, beliefs, or arguments. Stephen Norris (1985) says it helps students to "apply everything they already know and feel, to evaluate their own thinking, and especially to change their behavior...." The most widely accepted characterization of critical thinking along these lines is due to Robert Ennis. According to Ennis (1985), critical thinking is reasonable, reflective thinking that is focused on deciding what to believe or do (p. 46).

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Critical thinking is not the same as, and should not be confused with, intelligence; it is a skill that may be improved in everyone (Walsh & Paul, 1988). However, it is not something that necessarily develops with maturity and so should be taught to all ages. The New Jersey Test of Reasoning Skills, for example, found that the mean scores of college freshmen tested were less than one point above the mean scores of sixth graders (Lipman, Sharp & Oscanyan, 1980). Several teaching strategies, such as classroom assessment techniques (Angelo, 1995), cooperative learning strategies (Cooper, 1995), problem-based learning strategies (Carder, Willingham & Bibb, 2001) and case study pedagogy (McDade, 1995) have been proposed to help promote CT (Yang, Newby & Bill, 2005).

Meanwhile, King (1995) and Taba (1966) suggested that the level of thinking that occurs is influenced by the level of questions asked. This is especially true in science education. Thus, teaching science by inquiry is proposed (Bybee, 2000). Learning, using the inquiry approach, involves students forming their own questions about a topic and having time to explore the answers. The students are both problem posers and problem solvers within inquiry learning. Inquiry as abilities includes identifying questions, designing and conducting scientific investigations, formulating and revising scientific explanations, recognizing and analyzing alternative explanations, and communicating and defending scientific arguments. It is suggested that many of these abilities are integral to CT. In addition, inquiry teaching and learning poses a challenge to both teachers and students (Kracjik, Mamlok & Hug, 2000).

However, in the traditional classroom, science is usually presented as a rigid body of facts, theories, and rules to be memorized and practiced, rather than a way of knowing about natural phenomena. And the idea that teachers are the most influential factor in educational change is not controversial (cf. Duffee & Aikenhead, 1992). The crucial role of teachers in traditional top-down approach gradually becomes obstacle of current science education. A worldwide reform of science education has been advocated, with one of the aims to focus on inquiry as a central element of the curriculum, to promote students to actively develop their understanding of scientific concepts, along with reasoning and thinking skills (Jan H., Douwe & Nico, 2001).

Laboratory activities have long had a distinctive and central role in the science curriculum and science educators have suggested that many benefits accrue from engaging students in science laboratory activities (Hofstein & Lunetta, 1982; Lunetta, 1998). More specifically, when properly developed, inquiry-centred laboratories have the potential to enhance students' constructive learning, conceptual understanding, and understanding of the nature of science. Inquiry-type experiences are especially effective if conducted in the context of, and integrated with, the conceptual development of the topic taught (Hofstein, Nahum & Shore, 2001). In addition, Hofstein and Walberg (1995) reported that inquiry-type laboratories are central to learning science, because students are involved in the process of conceiving problems, formulating hypotheses, designing experiments, gathering and analyzing data, and drawing conclusions about scientific problems or science phenomena. This has the potential to improve students' CT skills through the inquiry-type experiment (Allison & David, 1972; Charen & George, 1970). Miri et al. (2007) suggest that if teachers purposely and persistently practice higher order thinking strategies such as inquiry-oriented experiments, there is a good chance for a consequent development of critical thinking capabilities. Domin (1999) concluded that the inquiry laboratory style gives students the opportunity to engage in authentic activities and has been proven to be beneficial in fostering critical thinking.

The aforementioned studies have provided valuable information indicating that students' CT skills can be fostered and demonstrated through inquiry experiment. However, research by Innabi and Elsheikh (2007) suggests that even teachers, who believe critical thinking is essential, feel unequipped to teach those skills. To improve students' performances on critical thinking, schools of education must improve teachers' critical thinking ability. The teacher educators must teach cognitive skills to preservice teachers before training them to teach these skills in the classroom (Ashton, 1988). Teachers in training who develop improved critical thinking strategies may in turn enhance their own students' analytical skills (Onoshko, 1990; Paul, Elder & Bartell, 1997; Mei- Yun, Swee, Jung & Leah, 2003; Marlow & Inman, 1992). Furthermore, Edward C. Warburton (2008) suggested that preservice education would seem to be a good time for interventions that promote optimal use of CT activities in the classroom. Nevertheless, researches of teachers' CT recently have concentrated on the influence of teacher beliefs about CT activities (Zohar, A., Degani, A., & Vaakin, E., 2001; Richardson, 1994, 1996; Torff, B., 2005, 2006; Torff & Warburton, 2005), strategies or approaches promoting teachers' CT skills are inadequate. There is a need to develop programs or projects in improving teachers' CT. The use of discovery or guided inquiry experiments for developing critical thinking in problem solving were advocated (Allen, J. B., 1986), and it seems to be an optimal approach in promoting CT skills (Allison & David, 1972).Thus, the main goal of this study was to conduct empirical research to ascertain the effectiveness of inquiry experiment in improving the preservice teachers' CT skills.

2. Methods

2.1. Design

To achieve the previously mentioned research aims, a pretest-posttest experimental design with an experimental group and a control group was employed. Students in the experimental group were allowed to use inquiry learning approach when conducting experiments, whereas students in the control group used the traditional way to do the experiments, using only the experimental materials, which were provided by the researcher. The California Critical Thinking Skills Test (CCTST) as data collection instrument was administered at the beginning and end of the program to all the participants. The pretest and posttest results for both groups were then compared to see whether there were any significant differences in the variables measured.

The design of the study can be diagrammed as follows:

O_1—X—O_2 ——Experimental Group

O_1—Y—O_2 ——Control Group

O_1——pretest, O_2——posttest, X——use of inquiry-based experiment, Y——use of traditional experiment.

2.2. Participants

The subjects sampled in this study were 42 fulltime senior students at Shaanxi Normal University in the northwest China who were chemistry preservice teachers. There were 20 preservice teachers in the experimental group and 22 in the control group. Their ages varied from 19 to 22 with average age of 20.55 years old. Before participating in the study, they have accepted several educational courses and also had the teaching practice experiences.

2.3. Instruments

To test the participants' level of critical thinking, the Chinese version of California Critical Thinking Skills Test (CCTST) (Form A) (Facione 1990, 1992) was used.

The CCTST developed by Facione is aimed at college/graduate students and adult professionals. The test consists of 34 multiple choice short problem statements and scenarios that are discipline neutral, targeting the core CT skills (analysis, evaluation, inference, deductive reasoning, and inductive reasoning) regarded to be essential elements in a college education. It takes 45 minutes to complete. One point is given for each correct answer, with the maximum score being 34. The test generates a total score and five subscale scores. When a person scores above 20, the person has high CTS; 15–19, medium CTS; and below 14, low CTS. The internal consistency Kuder-Richardson 20 of CCTST is 0.70 for Form A.

The California Critical Thinking Skills Test was modified by Luo and Yang in 2002. The Chinese-version CCTST yields an overall score (0–34) on critical thinking skills, Pearson r=0.63, $p<0.01$, $r/2$= (0.75-0.80), $p<0.01$, and three subscales: analysis (A) (0–9); evaluation (E) (0–14); and inference (Inf) (0–11), which shows a good reliability, and good construct validity.

2.4. Procedure

To ensure that the treatment administered to participants in the experimental and control groups was similar, the same curriculum and lesson plans were used and the same teacher conducted the lesson. In addition, the researcher introduced the concept of CT to all the participants before the program to ensure that they were capable of using it.

In this study, a series of 10 chemical experiments were chosen as the main instructional materials because they were part of the conceptual development of chemistry key concepts (e.g. acids-bases, oxidation-reduction, bonding, reaction rate) and the application of chemistry in actual life (e.g. cloth diapers, corrosion of iron nail, pigments in candies) (see Table 1).

Table 1. Summary of Experimental Topics

Experimental topics
Activity comparison of Na, Mg, Al and Zn
Analyzing the influencing factors of H_2O_2 decomposition reaction rates
Super absorbent resin—“cloth diapers”
The main composition of toothpaste and match
Oxidation-reduction reaction and primary battery
The corrosion of iron nail in different conditions
The test of Iodine in the kelp
What pigments are included in the candies?
The self-made natural acid-base indicator
Ionic bond or covalent bond?

Above all, the participants were randomly assigned to experiment and control groups. A pretest of CT skills level was administered to all the participants before the program. At the beginning of the program, the researcher randomly divided the experimental group of 20 students into small groups of 2-3 students. There were a total of 8 small experimental groups in this study, and each experimental group could choose 3-5 experiments in the scheduled topics (can not be repeated) for their interests. Students in experimental group must conduct experiments in inquiry way, the experiments which they conducted we called inquiry chemical experiment. These inquiry chemical experiments must include designing and planning the experiment, interpreting the results and arriving at a scientific conclusion. In the past, Herron and Pella (Hofstein, 1988) suggested the idea of ‘degree of freedom’ given in the laboratory to describe the level of inquiry for each of the experiments. The inquiry chemical experiments that were developed range from those which are totally ‘open’ to investigation to those in which the student is asked to conduct only a partial inquiry. The detailed descriptions of the experimental process, which include the inquiry activities focused on, the instructions given to the experimental group are tabulated in Table 2. On the other hand, the control group could also choose their interested experiments the same as the experimental group. What different was that the control group continued with step-by-step verification laboratory exercises, working in pairs with direct supervision and instruction. After two months of the treatment, a posttest of CT skills level was administered to all the participants to examine their CT skills level.

Table 2. Components of Inquiry-based Experiments and Instructions Given to Experimental Group Regarding the Performance of Each Component

Component of inquiry-type experiment	Instructions given to experimental group
Definition of the problem (hypothesis) and asking relevant questions	Try to define the problem and to hypothesise.
Planning of the experiment	Try to plan your experiment accurately, logically, interestingly and efficiently. Present your assumptions at each stage, act independently, and prepare an equipment list.
Performance of the experiment	Follow the safety rules (and instructions); use the proper tools and be careful with the materials.
Observation of phenomena	Observe carefully the materials and changes that occur during the experiment and write them down in your notebook.
Organising and analysing of data, Use concise, exhaustive expressions; refer to interpretations, and conclusions	Use concise, exhaustive expressions; refer to unclear observations; distinguish between assumptions, explanations and conclusions and reports. Organise your findings in tables or graphs.

3. Results

Summary statistics (descriptive) of the CCTST results before and after the implementation of the inquiry-based experiment are presented at Table 3. Regarding the total score of both groups, experimental group showed consistently higher critical thinking skills levels before and after the program. The experimental group scored a mean of 11.60 at the beginning of the program and 13.10 after the program, versus the control group who scored means of 11.59 and 11.64, respectively.

Table 3. Pretest and Posttest Means of Scores

	Group	N	Pretest M	Pretest SD	Posttest M	Posttest SD
Total score	Exp	20	11.60	2.11	13.10	2.38
	control	22	11.59	2.17	11.64	2.15
Analysis	Exp	20	3.80	1.51	5.05	1.79
	control	22	4.00	0.93	4.05	1.00
Evaluation	Exp	20	4.30	0.98	4.80	1.11
	control	22	4.68	1.62	4.63	1.62
Inference	Exp	20	3.50	1.28	3.55	1.25
	control	22	2.91	0.75	2.95	0.72

Differences between experimental group and control group with regard to pretest and posttest were examined using independent samples t-tests (equal variances assumption was verified via a Levine's Test, $p>0.05$ in all cases). As shown in Table 4, the total score and the analysis subscale score of the post test between the experimental group and the control group showed significant different, whereas no significant differences were found for the total score and all the subscales of the pre test. Evidently, the control group had less improved in comparison with the experimental group.

Table 4. Independent Samples T-test for Treatment and Experimental with Control Group as Variables (N = 42)

	Exp-Control group	t	p
Total score	Pre test	0.014	0.989
	Post test	2.093	0.043
Analysis	Pre test	-0.523	0.604
	Post test	2.272	0.029
Evaluation	Pre test	-0.936	0.356
	Post test	0.379	0.707
Inference	Pre test	1.805	0.081
	Post test	0.925	0.362

As shown in Table 5, the statistical difference for the pre-post test of the experimental group was determined using paired samples t-tests for the total score and the subscale scores of CCTST; significant differences were found for total score of CCTST [$t=-2.881$; $p=0.010$ (<0.05)], and the subscale scores of analysis [$t=-2.763$; $p=0.012$ (<0.05)] and evaluation [$t=-2.236$; $p=0.038$ (<0.05)] as the t-tests conducted. The statistical difference for the pre-post test of the control group was determined correspondingly with paired samples t-tests for the total score and the subscale scores of CCTST; furthermore, no significant differences were found for the total score and all the subscales of the control group.

Table 5. Paired Samples T-test for Treatment and Posttest with Pretest as Variables (N = 42)

	Pre-Post test	t	p
Total score	Exp	-2.881	0.010
	Control	-0.295	0.771
Analysis	Exp	-2.763	0.012
	Control	-0.370	0.715
Evaluation	Exp	-2.236	0.038
	Control	0.370	0.715
Inference	Exp	1.097	0.287
	Control	-1.000	0.329

4. Discussion

Results indicated that the students in the experimental group significantly improved their levels of critical thinking skills after participating in the program. However, the control group did not significantly enhance their critical thinking skills levels. This outcome provided additional support that teaching chemistry with inquiry-based experiment is an effective model for increasing critical thinking skills of chemistry college students (Allison & David, 1972). Although the critical thinking skills in both groups were in the low range, the difference in the critical thinking skill points scored by the experimental group was found to be statistically significant. This adds support to the viewpoint that inquiry learning enhances the ability of students to integrate theory with practice and engage in critical thinking.

In the study, there was a significant difference in the "analysis" and "evaluation" subscale scores of critical thinking skill of experimental group after the inquiry experiments were implemented. The analysis subscale measures the skill of categorization, decoding significance, and clarifying meaning. A high score in this subscale shows that the individual has a greater ability to comprehend and express the meaning or significance of a wide variety of experiences, situations, data, events, judgments, conventions, beliefs, rules, procedures or criteria (Facione, 1990). It is believed that the difference in this subscale may be due to the emphasis in inquiry experiment on developing preservice teachers' collecting and interpreting of information, analyzing arguments and expressing their beliefs or opinions skills. The pre-post test of experimental group also differed significantly on evaluation, which reflects a person's abilities of justifying and assessing the arguments. The evaluation may be relate to the focus on experimental procedure, during which preservice teachers assess the credibility of statements and justify their reasoning based on relevant evidence, concepts, methods or standards (Facione, 1990). The lack of difference in the inference subscales is worthy of further investigation.

In a word, all these results indicated that the inquiry experiment actually improved the participants' critical thinking skills, which are consistent with the evidence reported by Robert David (1972) and Miri et al. (2007).

5. Conclusion

CT is an important issue in higher education especially in teacher education, and educators have continued to focus on the development of CT in learners. This study focused on investigating the effectiveness of using inquiry-based experiment to enhance preservice teachers CT skills. The results corroborate findings from other studies that found critical thinking skills are enhanced when active learning approaches like inquiry experiment are used. "Analysis" and "evaluation" subscale scores of experimental group were also higher than their pretest scores as well as the comparison group. However, there are limitations to the study that must be acknowledged. The preservice teachers did not achieve high levels of CT in either the inquiry or the traditional approaches, nor did they score high or differ significantly on subscale of inference. This suggests that studies of the development of teachers' CT are still needed.

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